External Air Assisted Shaping of Fuel Spray for Gas Turbine Combustor

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***Abstract*—In this investigation an attempt has been made to understand the mechanism for changing fuel spray pattern by using different geometrical shapes of air flow orifices at atomizer exit. An airblast atomizer has been specially designed and constructed for studying fuel spray pattern. The results of this investigation indicate that an appropriate air orifices help to obtain desired elliptical fuel spray patterns. This may enable uniform combustion exit temperature or improved pattern factor of Gas turbine combustor. Besides this, the results obtained in this research work may be useful in multiple applications like development of better spray drying, spray painting, spray cooling systems and formation of nano-particles.**

***Index terms*—airblast atomizer, airflow orifices, elliptical spray pattern, combustion exit temperature.**

I. Introduction And Scope Of Present Research Work

The spray pattern from an atomizer affects the temperature distribution at the exit of combustion chamber. Non-uniformities in the exit temperature profile of the combustor currently limit the performance of Gas turbine engines. This causes damage to liners and turbine blades further it also lead to problems in cooling system. Literature survey[(1) to (8)] indicates that non symmetrical spray flames and the hot-streaks that can cause serious damage to the combustion liner and can severely affect the combustor exit temperature distribution. These issues are related to the spray pattern provided by particular atomizer configuration, so elliptical spray pattern could be solution for uniform distribution of the fuel-air mixture along the circumference of the annular combustion chamber to achieve uniform combustion exit temperature. It has been reported that controlled spray pattern will facilitate the use of single spray device for multiple applications like spray drying, spray painting, spray cooling and formation of nano-particles. Therefore, in this research work, experiments have been proposed to understand the mechanism to change fuel spray pattern by using different orifice plate geometry at the atomizer exit. In the first phase of this investigation it has been proposed to design and construct an airblast atomizer with specially designed air orifice plates to facilitate the fuel spray pattern studies. In the second phase of the investigation it has been proposed to study the spray patternation of full cone spray nozzle for different liquid flow rate without air flow. Lastly in the third phase of the investigation it has been proposed to study the spray discharging from airblast atomizer with orifice plates having different air flow orifices arranged in a specific pattern at different air flow conditions to understand the role of orifice plate geometry on the spray patternation.

II. Experimental Methodology

The cross sectional view of Airblast atomizer designed, fabricated and used in the present investigation has been presented in Fig.1. It comprises of three major components: Central fuel nozzle, annular air flow chamber and air orifice plate. Central fuel nozzle of Full cone spray nozzle used in the present study was imported from Spraying System Com, USA. Annular air flow chamber comprised of two major components: A cylindrical chamber segment and a converged segment. The length and inner diameter of the cylindrical chamber segment were kept at 60mm and 75 mm respectively. The cylindrical chamber segment was connected to high pressure air flow line via two circular holes was kept at 50mm. The converged segment of the annular air flow chamber was of length 35mm. An O ring was placed between the cylinder chamber segment and converged segment to avoid air leakage. The exit portion of the converged segment was designed to position the orifice plate. The orifice plate was arranged tight-fit at the bottom portion of the converged segment of the annular air flow chamber arrangement. The air orifice plate comprises of air flow orifices arranged in a specific pattern. Three different plates shown in Fig. 2 referred here as OP1, OP2, and OP3, were used to alter the spray pattern. The three orifice plates differ mainly in the arrangement of air flow orifices. The air flow area of the air orifice plates were kept constant as 31.41 sq. mm (approximately).

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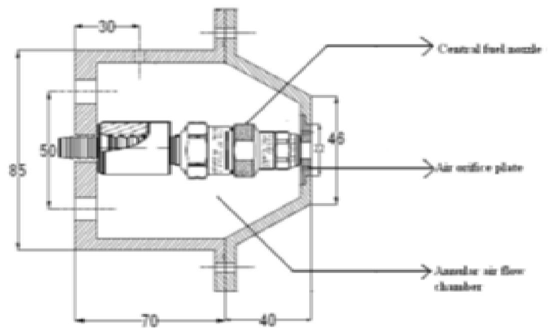

Figure.1: Cross sectional view of airblast atomizer designed and fabricated in the present investigation.

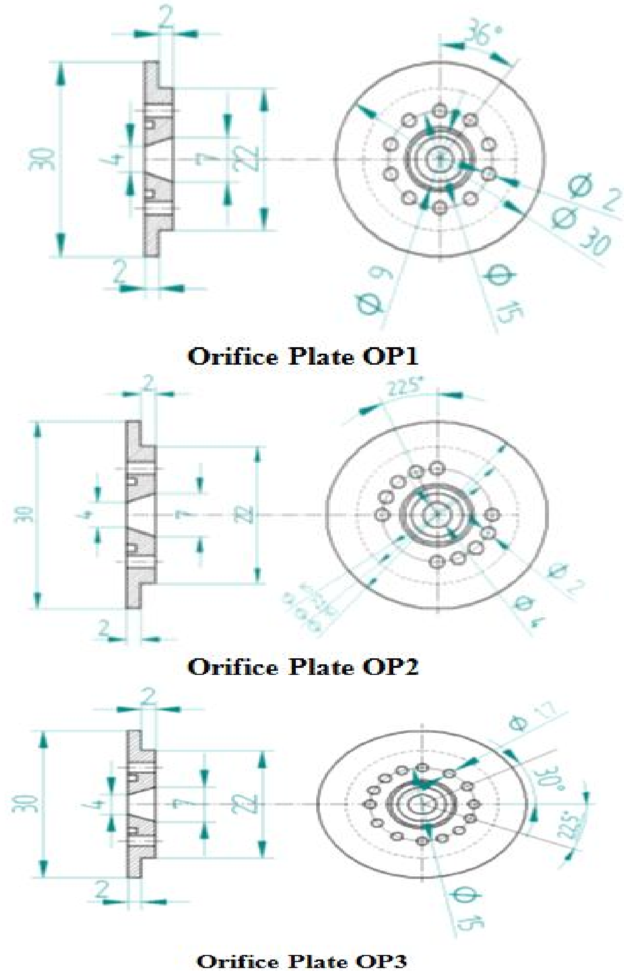

Figure.2: Orifice plates with constant airflow area but with different arrangement of flow orifices used in this investigation.

A. Spray test facility details

The schematic view of spray test facility used in this research work has been presented in Fig. 3 consists of a water tank that is being pressurized by compressed air delivered by the reciprocating compressor. The compressor can deliver air up to 30 bar pressure is connected to the injector nozzle which placed centrally in airblast atomizer with flexible steel piping and manual needle valves are used to meter the water flow through pressure gauge that reads pressure drop across the injector. A metallic spray chamber which is 600 mm in diameter and 800 mm in height is used for conducting spray tests. The four sides of the chamber consist of circular openings to provide optical access and below there was a opening to collect water in a unit situated right below assembly. The liquid spray from the airblast atomizer is injected inside the spray chamber into still ambient air and atomizer was mounted such that it can be moved vertically to adjust the height from the fixed 1 D mechanical patternator. A steel mounting plate and fixing rods is used to attach airblast atomizer which in turn fixed to traverse which can be rotated by 360 degree to position the airblast atomizer for different positions with respect to patternator and camera. Water is used to simulate the liquid fuel in all of the spray tests. In the present study, specific attention was given to measure the radial spray distribution of sprays discharging from the airblast atomizer by employing 1 D mechanical patternator system. A mechanical patternator collects the sprayed liquid from different locations into cells for a given time, and the volume of the collected liquid is subsequently measured to understand the radial spray distribution. The flow behavior of liquid spray discharging from the airblast atomizer was analyzed by capturing its photographic images with the aid of an image acquisition system shown in Fig. 4(a) comprising a camera and a lighting device. Nikon D300 digital camera was used to take photographs of the spray. A high intensity strobe light was used to illuminate the spray. The strobe light was operated under backlighting along with a light diffuser arrangement. The frequency of light flash and the camera exposure time were so adjusted that the camera captures a single flash during an experimental run. The entire liquid spray was obtained without any spatial discontinuity and aberrations. The images were analyzed by means of commercially available IMAGE J image processing software.

B. Spray Pattern Measurements details

The flow rate of water discharging from the full cone Spraying system nozzle measured by means of collection method. The volume flow rate of air discharging from the orifice plate (air jets) was measured by employing Micro Motion flow meter. The images of liquid spray captured during the experimental runs were used to extract the following: spray width (SW) at different locations (Z) from the orifice exit and at different positions with respect to atomizer. The measurement of spray width and radial spray distribution has been schematically illustrated in Fig. 4(b). The airblast atomizer was placed in the spray chamber and fixed to a traverse. First uniform liquid spray was ensured from a spraying system nozzle placed inside the annular air flow chamber. Then the center of the injector orifice was brought to the center of the patternator. The axial distance between the injector face and the patternator face was kept at 3 inches. The patternator was exposed to the spray for 2 minutes and sample is collected in the test tubes. Then the quantity of water collected in each test tube is measured and recorded. The first experiment is carried out without air interaction with the spray for liquid pressure drop of 60psi. The same is repeated for different orifice plates and varying air flow conditions from 1psi to 12psi.

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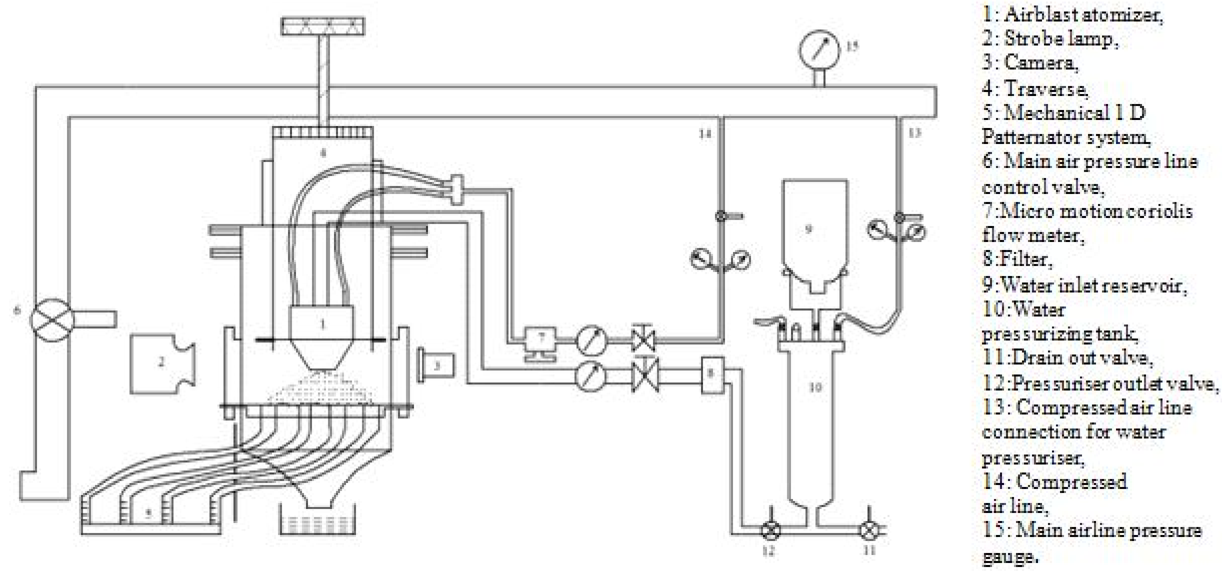

Figure 3: The Schematic view of spray test facility used in this investigation

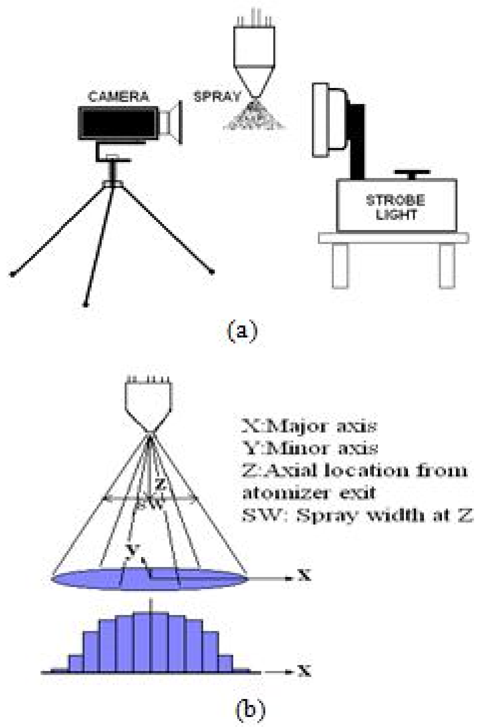

Figure. 4: (a) schematic view of Camera and lighting arrangement for the imaging of liquid spray. (b) The schematic illustration of spray width measurement and radial spray distributuion.

III. Results And Discussions

In the initial part of the investigation, air blast atomizer has been designed and fabricated to study the effect of external air jets on the full cone spray. Different orifice plates of same flow area are used to alter the spray pattern. It is possible to conduct the experiments of radial spray distribution of spray and visualize liquid spray pattern successfully for wide range of flow conditions. Images of the spray can be captured by photographic method. Subsequently by analyzing these images it is possible to elucidate the role of external air jets on the full cone spray. A mechanical 1D patternator has been employed to collect the spray samples for radial spray distribution studies. Further, by using the experimental setup, spray pattern using different air orifice plates can be compared.

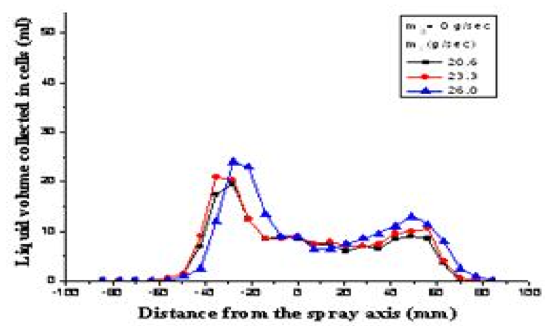

Figure.5: Typical results of Radial spray distribution of spray discharging from the full cone nozzle without air flow

A. Radial spray distribution of spray without air

Typical results of radial spray distribution of spray discharging from the full cone nozzle without air flow have been presented in Fig. 5. It can be observed that, the spray liquid is confined to the central region of the spray and spray discharging from full cone nozzle appears to exhibit asymmetry. Further, at given radial locations the volume of liquid collected increases with the increase in the mass flow rate of the liquid (m_l). However, the effect has been found to be less effective for high liquid flow conditions.

B. Spray width and radial spray distribution of spray with air.

As mentioned earlier, spray discharging from the airblast atomizer with different orifice plates and with different air flow conditions has been studied. The typical spray width and radial spray distribution of spray when orifice plate (OP1) comprising of 2mm air flow orifices arranged uniformly in the circular line with diameter 15mm is used has been presented in Fig. 6 and Fig. 7. It can be observed that interaction of

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external air jets on full cone spray leads to nearly circular spray pattern (Fig. 6). Air flow conditions have an influence on the shrinkage of the spray in all 360 degree. With increasing air mass flow rate (m_g), the spray liquid volume is getting more and more confined to central region and changes the spray distribution (Fig. 7). Thus the air flow appears to limit the spreading of liquid spray volume in the radial direction. However, this effect has been found to be less effective for high air flow conditions. The usage of this pattern of orifice plate develops symmetric spray pattern. The typical spray width and radial spray distribution of spray when orifice plate (OP2) comprised of 2mm air flow orifices arranged in a specific pattern in the circular line with diameter 15mm is used has been presented in Fig. 8 and Fig. 9. It can be observe that interaction of external air jets on full cone spray leads to near elliptic spray pattern (Fig. 8). The airflow conditions have an influence on the shrinkage of the spray in the direction of air jets but no shrinkage has been observed in the other direction of the spray. With increasing air mass flow rate, the spray liquid volume is getting more and more confined to central region due to the spray confinement caused by the air flow (Fig. 9) Thus, the presence of air orifices influences the spray shape pattern. However, this effect has been found to be less effective for high air flow conditions. The usage of this pattern of orifice plate develops asymmetric spray pattern owing to the asymmetric arrangement of air orifices in its surface. The spray droplets are deflected only in the region where the air jets are present. A photograph of images of typical spray has been presented in Fig. 10. The typical spray width and radial spray distribution of spray when orifice plate (OP3) comprised of 1.7mm air flow orifices arranged in a specific pattern in the circular line with diameter 15mm is used has been presented in Fig. 11 and Fig. 12. From Fig. 11 it can be observed that the trend of results has been found to be similar to the trend of results obtained when 2mm diameter airflow orifice plate (OP1) was used. However, more confinement of the spray was observed at locations where more air jets have been located (Fig. 12)

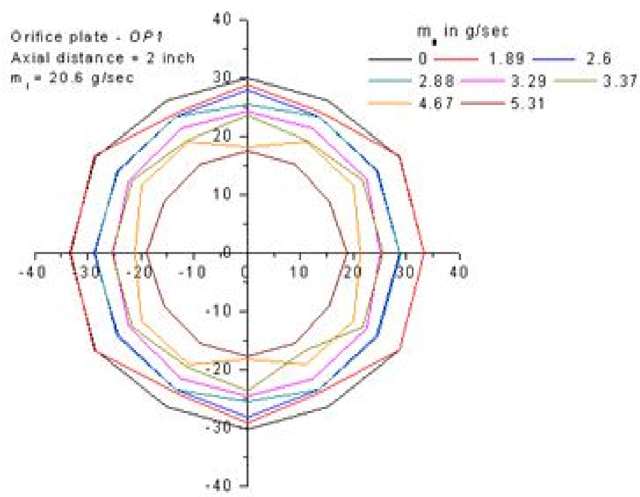

Figure 6: Spray width at axial distance Z=2 inches from the orifice exit when orifice plate (OP1) comprising of 2mm air flow orifices arranged uniformly in the circular line with diameter 15 mm is used.

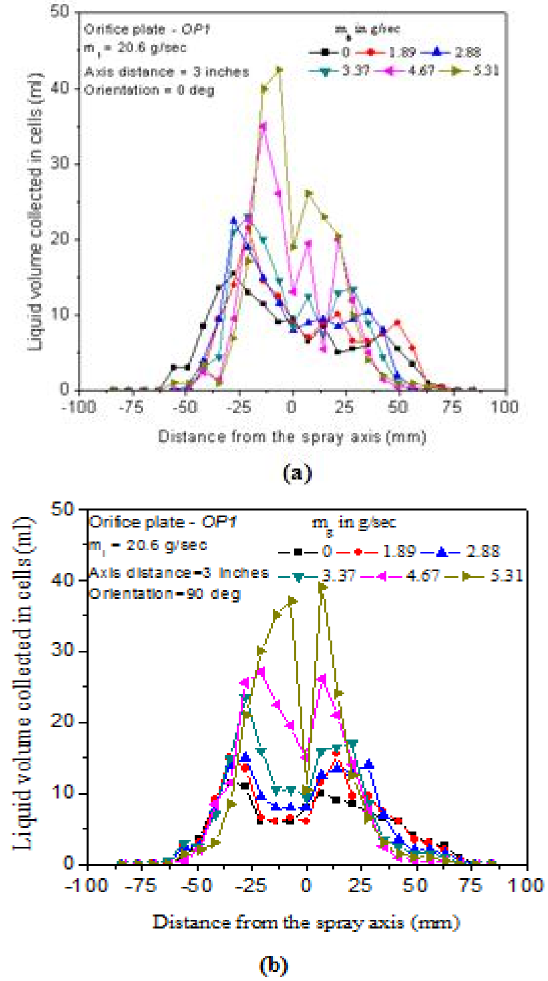

Figure 7: Radial spray distribution when orifice plate (OP1) compressing of 2mm air flow orifices arranged uniformly in the circular line with diameter 15 mm is used (a) 0^0 position, (b) 90^0 position of airblast atomizer with respect to patternator.

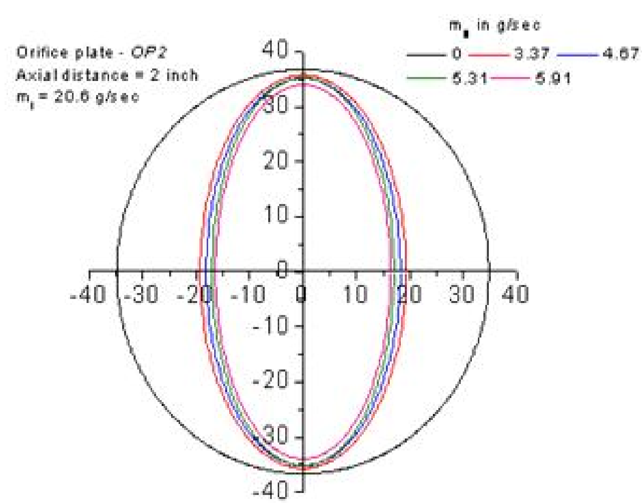

Figure 8: Spray width at axial distance Z=2 inches from the orifice exit when orifice plate (OP2) comprising of 2mm air flow orifices arranged in a specific pattern in the circular line with diameter 15 mm is used.

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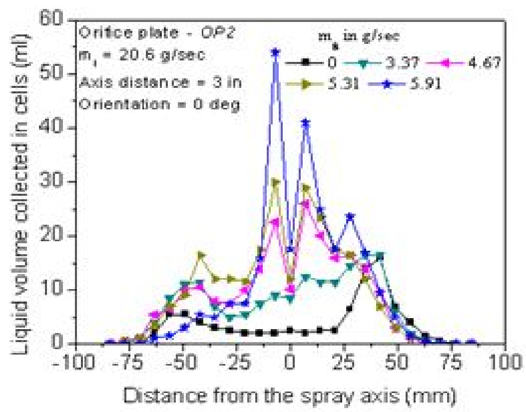
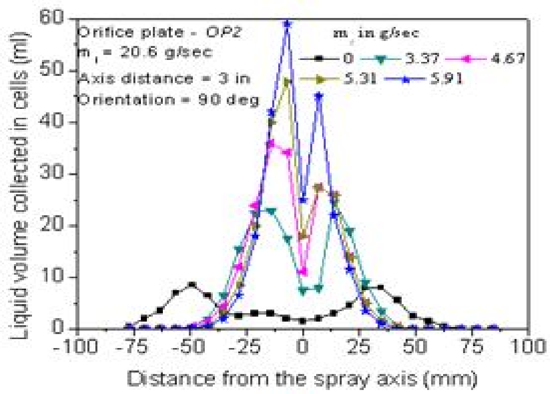


(a)



(b)

Figure 9: Radial spray distribution when orifice plate (OP2) compressing of 2mm air flow orifices arranged in specific pattern in the circular line with diameter 15 mm is used (a) 0^0 position, (b) 90^0 position of airblast atomizer with respect to patternator.

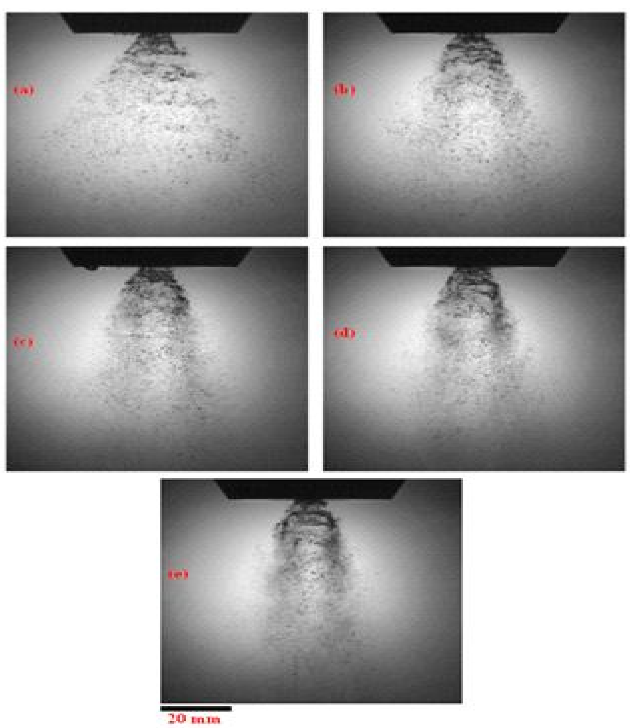


Figure 10: Photograph of typical spray pattern at constant liquid injection pressure of 60psi and at different air pressure drops (a) air pressure drop 0psi (b) air pressure drop 5psi (c) air pressure drop 8psi (d) air pressure drop 10psi (e) air pressure drop 12psi

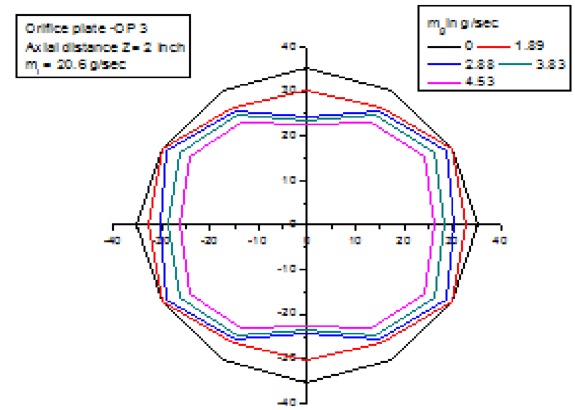
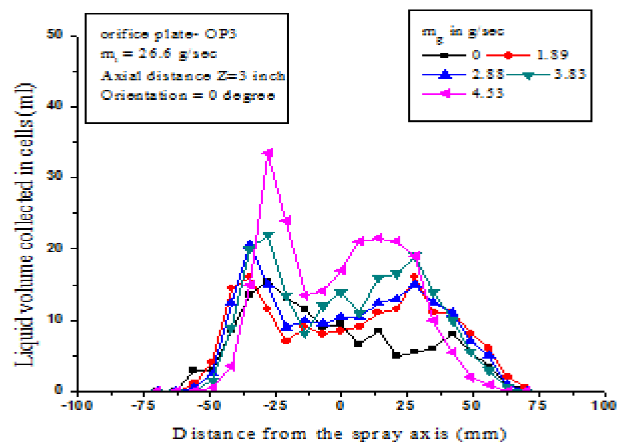
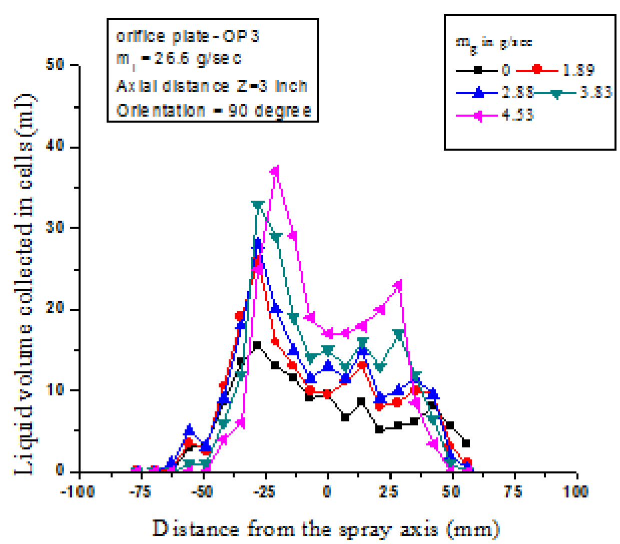


Figure 11: Spray width at axial distance Z=2 inches from the orifice exit when orifice plate (OP3) comprising of 1.7mm air flow orifices arranged in a specific pattern in the circular line with diameter 15 mm is used



(a)



(b)

Figure 12: Radial spray distribution when orifice plate (OP3) compressing of 1.7mm air flow orifices arranged in specific pattern in the circular line with diameter 15 mm is used (a) 0^0 position, (b) 90^0 position of airblast atomizer with respect to patternator.

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Conclusions

In this investigation an attempt has been made to understand the mechanism for changing fuel spray pattern by using different geometrical shapes of air flow orifices at atomizer exit. An airblast atomizer has been specially designed and constructed for studying fuel spray pattern. The results of this investigation indicates that an appropriate air orifices at the atomizer exit help to obtain desired elliptical fuel spray patterns. This may enable uniform combustion exit temperature or improved pattern factor of Gas turbine combustor. Besides this, the results obtained in this research work may be useful in multiple applications like development of better spray drying, spray painting, spray cooling systems and formation of nano-particles.

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